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COATING OF STEEL PISTONS WITH BEARING MATERIALS, PHASE 1.(U)
OCT 80 M SOLANKI
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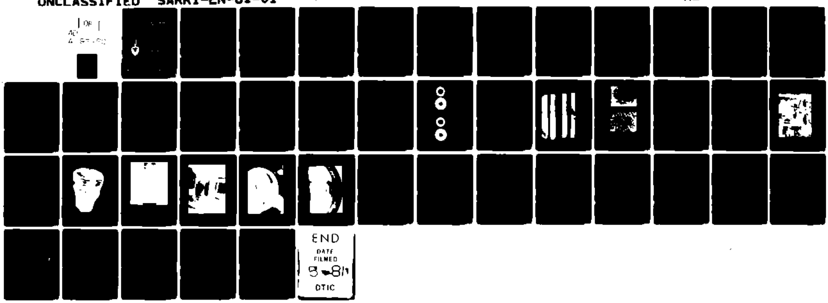

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COATING OF ~~WEAPON COMPONENTS~~ WITH BEARING MATERIAL (Phase 1)

M.SOLANKI

DECEMBER 1980

TECHNICAL REPORT

ENGINEERING DIRECTORATE

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5. GMAW (Gas Metal Arc Weld)
6. Wear

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Nodular iron pistons for the M174 Recoil Mechanism characteristically yield less-than-desirable service lives; the deficiency being attributed to a lack of fracture toughness of the iron. Consequently, cast steel pistons clad with a bearing material, required since the steel does not offer the built-in lubricity indigenous to nodular iron, were considered as an alternate material.

Cost-effective Gas Metal Arc Welding (GMAW) processing techniques were developed to provide an aluminum-bronze bearing surface to the steel pistons. Concurrent

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laboratory tests were conducted on welded specimens to simulate live-firing performance. The tests included chemical, mechanical and metallurgical analyses. After development of the GMAW procedure, including selection of an aluminum-bronze bearing material, a coated steel piston was manufactured at Rock Island Arsenal and subjected to firing tests. Its performance in the Arsenal simulator followed by live-firing at Yuma Proving Ground exceeded all requirements.

Future studies will provide more clad steel pistons for firing tests to verify material performance. In addition, strip welding and explosive bonding methods will be evaluated to determine the least cost method of cladding steel components with aluminum-bronze.

FOREWORD

The work was authorized as part of the Manufacturing Methods and Technology Program of the U.S. Army Materiel Development and Readiness Command and was administered by the U.S. Army Industrial Base Engineering Activity.

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1.0 INTRODUCTION:

The objective of this project is to develop cost effective manufacturing methods to coat weapon components with bearing materials for improved performance. The first phase of the work was directed to the manufacture of a steel piston for the M174 Recoil Mechanism which is not prone to failure by fracture of the piston body and which exhibits significantly greater bearing wear life when compared to the one-piece cast nodular piston currently in use. The use of nodular iron in production has been desirable since its microstructure offers "built-in" lubricity. However, the attainment of a homogeneous microstructure is most difficult and, if possible, very costly when casting non-uniform wall thicknesses typical of the piston. Therefore, low alloy steel was substituted for the nodular iron to impart adequate performance characteristics to the piston.

The use of steel for pistons dictates that a bearing material must be applied to surfaces since the steel does not afford the built-in lubricity of nodular iron. Several methods to coat the steel with bearing materials, e.g., flame spray, arc spray, etc., have been used. Sprayed castings may have an inherent advantage, i.e., they are less than fully dense (approximately 20 - 25% porosity) after being applied to the substrate and this might impart some self-lubricating quality to the material. However, this possible advantage is far outweighed by the coatings having low adhesive strengths (generally less than 1,000 psi), and being subject to brittle failure because of the formulation of oxide layers on metal particles. The oxide layers formed make surfaces hard and abrasive thereby reducing the bearing quality of the material. Consequently, their function as bearing materials is quite limited. In addition, the application of sprayed coatings to the inner diameter surfaces of certain components is often inhibited by the space available. That is, proper tool-to-workpiece distances are not possible when coating interior surfaces. It is, therefore desirable to define improved methods to coat pistons with bearing materials. The following are methods to be evaluated in Phase 1 and Phase 2.

1.1 GMAW Welding: (Phase 1)

The use of Gas Metal Arc Welding (GMAW) methods to apply bronze bearing materials to inner and outer surfaces of the pistons was investigated. The reasons for its selection are attributed to its high bond strength (equivalent to the yield strength of the material) and very low porosity and oxide contamination when compared to flame and arc sprays. As the bearing material is welded to the substrate, the mechanically-bonded interface typical of sprayed metals is eliminated; hence, highest interface strengths are available. Also, automation of the welding operation is possible, thereby reducing process variables. The primary caution is concerned with the avoidance of a complete reheat treatment being required after welding. This is accomplished by minimizing the effects of high localized heat-input to the metallurgical condition of the steel, i.e., by adapting adequate cooling methods and by interrupting the welding process at required intervals.

1.2 Strip Cladding: (Phase 2)

The use of strip cladding (modified submerged arc welding) methods to apply thin metal strip rather than wire to substrates will be investigated in Phase 2. This process is characterized by high deposition rates, i.e., 40-55 lbs/hr, when compared to GMAW welding processes which characteristically deposit approximately 20-25 lbs/hr or metal arc spray methods which impart about 25 lbs/hr. Because of the lower heat input and lower dilution of filler metal and substrate, post heat treatment requirements are further minimized. In addition, the strip cladding procedures are more amenable to automation techniques. Some development of the strip cladding process is required before it can be used, therefore, it was decided to use state-of-the-art GMAW methods for the Phase 1 study.

2.0 MECHANICAL, CHEMICAL AND METALLURGICAL ANALYSES:

To evaluate important properties of bearing material and processes of cladding by simulation and live firing tests would be difficult and very expensive. Consequently, chemical, hardness, wear and friction, tensile and shear (bond) strength test and metallographic analyses were conducted in the laboratory. These tests were carried out for better understanding of material performance.

A low alloy steel plate (20" x 12" x 0.5") was clad with Al-Bronze (Ampcotrode 46) using the following welding parameters:

Voltage: 28-29 V
Current: 260-300 amp
Slope: Flat
Travel speed: 20 in/min
Shielding Gas/Flow Rate: Argon/35 CFH
Cooling: Water spray
Preheat: None

After being coated with Al-Bronze, the test plate was tempered at 1000°F for 2 hours. Various specimens were then machined for laboratory testing.

2.1 Chemical Analysis:

Chemical composition of steel plate was determined by using optical emission spectrographic techniques and chemical analyses of filler wire and the clad deposit was accomplished by wet chemical analysis. The chemical composition of the bearing alloy and steel substrate are presented in Table 1.

TABLE 1

CHEMICAL COMPOSITION

Chemical elements (weight %)

Steel Substrate

C	Si	Cu	Mn	Ni	V	P	Cr	S	Mo	Fe
0.287	0.304	0.125	0.518	0.065	0.003	0.0011	0.983	0.0123	0.221	Balance

Ampco-trode 46 (filler wire)

Cu	Ni	Fe	Al	Mn	Zn	Sn	Pb	Si
81.2	4.3	4.1	9.1	1.08	0.006	0.04	0.002	0.03

Clad Deposit

Cu	Ni	Fe	Al	Mn	Zn	Sn	Pb	Si	Other
76.4	3.8	7.2	8.9	1.02	.005	0.06	0.003	0.06	2.5

During weld cladding operations, it is desired to minimize dilution of the deposit. If the iron content in the deposit exceeds 10%, then a hard, iron-rich phase is formed that reduces the bearing quality of the coated surface. But by using filler wire of proper chemical composition and adequate cooling, it is observed that the iron content in the deposit was limited to 7.2%.

2.2 Hardness Analysis:

Hardness determination of test steel plate is presented in Table 2. As desired, the hardness of the bearing material was about 50 points Brinell lower than the steel substrate.

TABLE 2
HARDNESS SURVEYS OF OVERLAYED STEEL PLATE

	Hardness
Bearing Material (Ampco-trode 46)	231 - 244 KHN (216 - 232 BHN)
Steel Substrate (QQ-S-681, Grade 4)	27 - 28 RC (265 - 271 BHN)

2.3 Friction Wear Tests:

2.3.1 Test Apparatus: The friction and wear properties of the bearing materials were determined using the Alpha LFW-3 Tester. The flat surface of a rotating annular ring is used in this machine to give area contact against a stationary flat surface. The apparent area contact can be varied by a change in the diameter or width of the annular ring. Bearing pressures with standard specimens vary from 400 to 20,000 psi and this can be increased by a reduction in the area of contact. Speeds are infinitely variable from 1.47 to 52.3 fpm, and oscillatory motion is possible from 6 to 227 cycles per minute (cpm). The machine is designed for testing dry or liquid lubricants in various atmospheres and at temperatures from room temperature to 1,200°F. A single channel recorder was used for continuous recording of frictional force. Temperature measurement was done by Heat-Prober Thermometer.

2.3.2 Specimen Fabrication: The bearing materials were machined to form the stationary disc specimens. The wearing surface of the specimens was prepared on a table grinder to 14 rms finish. Final dimensions of bearing disc are shown in Figure 1a.

The mating material (4130 steel) was machined to form the oscillatory ring specimens. The wearing surface of these specimens was surface ground to a 20 rms finish. Final dimensions of the steel ring are shown in Figure 1b.

2.3.3 Test Procedure: The LFW-3 specimens, when initially received from the machine shop, were wiped and sprayed with naptha petroleum solvent. Before and after each LFW-3 test, the specimens were washed consecutively in methanol and petroleum ether. The specimens were blown dry and weighed.

Initially, the bearing and the mating test specimens were weighed to the nearest 0.1 mg. The specimens were then mounted in their respective positions and covered with hydraulic fluid (MIL-H6083D). The LFW-3 test conditions were those involving a 120° angle of oscillation at a frequency of 120 cycles per minute (64 inch per second linear velocity). The tests were conducted for durations of 10 and 60 minutes. The pressure during the first 60 seconds was 200 lbs/in^2 and was followed over the next 60 seconds by an increase in load to pre-set pressures of 500, 1000 or 1500 lbs/in^2.

The variables measured in each LFW-3 test were co-efficients of friction (μf), friction generated temperature (T), and total wear. The initial co-efficients of friction (μf initial) were determined immediately after full load was reached. Final co-efficients of friction (μf final) were determined just before the end of the test period. The temperature of the hydraulic fluid covering the wear specimens was monitored continuously.

After completion of the test, both the mating and bearing LFW-3 specimens were visually examined, and the weight loss or gain of each was determined. The visual examination consisted of inspection for evidence of discoloration, type of wear and metal transfer.

2.3.4 Results and Discussion:

Under all experimental conditions used, the co-efficient of friction for Al-Bronze is twice that of nodular iron (see Results, Table 3). It was observed that for the shorter time duration test (1 min.), nodular iron shows less wear than Al-Bronze. But for the one hour test at higher load (1500 lbs), the nodular iron surface and mating steel surface experienced severe galling (Figure 2a), whereas under the same experimental conditions the Al-Bronze surface revealed medium galling (Figure 2b). A possible explanation for this is that under higher loads for long time, graphite particles imbedded in the nodular iron matrix are gradually eroded from the surface causing the material to lose its natural lubricity.

2.4 Shear and Tensile Test:

2.4.1 Procedure: The particular tensile/shear test specimen design is used to measure bond strength in shear and also tensile strength of cladding materials (see Figure 3).

Both the tensile and shear specimen are pulled in tension. The shear specimen, however, has a smaller interface between the overlay and the substrate. Therefore, a larger shear stress is experienced when the shear specimen receives the same load as the tensile specimen. If the bond strength of the interface in shear is greater than the yield strength of the overlay in tension, then the specimen will fail in the bearing material. If the reverse situation is true, the specimen will fail in shear at the interface region.

2.4.2 Results: In all the tests, failure occurred through the clad material in Figure 4. Measured tensile strengths were between 75 to 94 KSI. This indicates that the bond strength in shear is much higher than the tensile strength of bearing material.

2.5 Metallographic Analysis:

The microstructures of weld deposits on the test plate are shown in Figures 5a and 5b. In Figure 5a, a columnar dendritic freezing pattern is evident in the copper-base weld. Crystals grew with a preferred orientation and the dendrite direction is parallel to the direction of heat flow. The gray interdendrite phase may be untransformed beta ($Al\ Cu_3$). This phase is retained on rapid cooling of the weld alloy. Such a structure is typical of as-cast copper alloys and is not harmful. No iron-rich phases were detected using the Scanning Electron Microscope. Nominal number of shrinkage cracks were discovered, depths ranging from 0.003 in. to 0.010 in. Since the weld alloy completely filled and bonded these cracks, they were judged to have produced no harmful effects.

Heat Affected Zone (HAZ) consists of bainite and ferrite structures as shown in Figure 6. These types of microstructures are desirable as they have higher toughness, hence re-heat treatment of component is not required.

TABLE 3

RESULTS OF FRICTION & WEAR TESTS

Test Set	Wearing Materials: Bearing Disc	Wearing Materials: Face Ring	Load Applied (lbs)	Friction Co-efficient (μ_f): Initial $(\mu_f)_i$	Friction Co-efficient (μ_f): Final $(\mu_f)_f$	Test time (min)	T_{max} (°F)
1	Ampco-trode 46	4130 steel	500	0.166	0.136	10	190
2	Ampco-trode 46	4130 steel	1000	0.226	0.151	10	280
3	Ampco-trode 46	4130 steel	1500	0.224	0.102	10	300
4	Ampco-trode 46	4130 steel	1500	0.230	0.126	60	400
5	Nodular Iron	4130 steel	500	0.108	0.107	10	180
6	Nodular Iron	4130 steel	1000	0.105	0.097	10	175
7	Nodular Iron	4130 steel	1500	0.099	0.092	10	170
8	Nodular Iron	4130 steel	1500	0.107	0.135	60	460

(Table 3 cont'd next page)

TABLE 3 cont'd
RESULTS OF FRICTION & WEAR TESTS

	Change in Weight at end of test (mg)		Initial Surface Finish (RMS)		Initial Hardness		Wear Type	
Test Set	Bearing Disc	Face Ring	Bearing Disc	Face Ring	Bearing Disc	Face Ring	Bearing Disc	Face Ring
1	-0.04	+0.05	10-14	15-20	22.5 R_c	35 R_c	1VL	1VL
2	-4.91	+0.27	10-14	15-20	22 R_c	34.5 R_c	2VL	1VL
3	-6.72	+0.91	10-14	15-20	22.5 R_c	35 R_c	2H, 5	2M, 3VL, 4
4	-37.05	+0.88	10-14	15-20	22.3 R_c	35 R_c	2M, 5	2M, 3VL, 4
5	-0.32	+0.62	12-16	15-20	97.5 R_B	34 R_B	1VL	1VL
6	-0.14	-0.03	12-16	15-20	98.0 R_B	35 R_B	2VL	1VL
7	-0.16	-0.15	12-16	15-20	99.0 R_B	35 R_B	2M, 4L	2M, 3
8	-125.3	-0.2	12-16	15-20	98.5 R_B	34.5 R_B	2S, 4H	2H, 3 5

LEGEND

1 - Smooth
2 - Galling
3 - Transferred Bearing Material
4 - Discoloration to blue - gray
5 - Discoloration to copper luster
VL - Very light
L - Light
M - Medium
H - Heavy
S - Severe

3.0 WELDING PROCEDURE FOR STEEL PISTONS:

Gas metal arc welding of steel pistons was initiated. The aluminum bronze family of alloys was proposed as the bearing material after considering ease of application by welding, toughness in service, and a confirmed history of successful application for use in reducing wear/friction when abraded by dissimilar materials. The particular selection of Ampco-trode 46 was made following the established practice whereby the bearing material should be 50 to 75 points Brinell lower in hardness than the mating surface.

3.1 Welding Parameters:

The following parameters were used in the welding process:

Inner Diameter:

Lathe Speed: 35 sec/rev (19.7 IPM on 3.660 in. O.D.)
Carriage Feed: 0.204 in/rev
Pulse: 36V, 1/6 cycle duration, DCRP
Background, 24V, DCRP
Current: 175-195 Amps
Shielding Gas/Flow Rate: Argon/35 CFH
Water cooled O.D.
Preheat: None

(Max. interpass temperature of body: 300°F, cooled with water spray back up for continuous weld.)

Outer Diameter:

Lathe Speed: 71.45 sec/rev (19.8 IPM on 7.5 in. O.D.)
Carriage Feed: 0.200 in/rev
Pulse: 36V, 1/6 cycle duration, DCRP
Background: 24V, DCRP
Current: 190 Amps
Shielding Gas/Flow Rate: Argon/35 CFH
Air cooled
Preheat: None

(No more than two revolutions were made without interruption for cooling.)

Figure 7 shows the desired dimensions for the Al-Bronze coated M174 Piston. Five test pistons were prepared at Rock Island Arsenal (RIA) for simulation and live firing test. A LINDE wire feeder and ST-9 modified torch plus AIRCO pulse arc power supply was used for welding pistons. The overall set-up of the process is shown in Figure 8.

Figure 9 (a & b) shows the torch position for I.D. and O.D. overlaying. After being coated with Al-Bronze, the pistons were tempered at 1000°F for 2 hours. Inspection of X-ray photographs of the pistons revealed a few minor voids,

less than about 0.094 in., and a material which was relatively free of micro-shrinkage. Window areas showed known defects related to prior weld repair of the steel piston and not related to the overlay. This was not of concern since the window areas were to be removed in final machining.

Figure 10 shows the M174 Piston with the Al-Bronze overlay on the outer diameter. After machining, the finished I.D. and O.D. thicknesses of the overlay were 0.060 in. (Figure 11).

4.0 FIRING TESTS AND ANALYSES:

4.1 Simulation Test and Analysis:

A steel piston clad with Al-Bronze was selected for simulation and live-firing tests. The simulation tests were conducted on a hydraulic gymnasticator at Rock Island Arsenal and a total of 3,025 rounds were fired.

On completion of simulation the gun mount was disassembled and both, piston and cylinder, were thoroughly cleaned and visual examination of surfaces was accomplished.

Bearing surfaces of the I.D. and O.D. of the piston were lightly scored as shown in Figures 12 and 13. This was mainly due to abrasion of hard chromium particles which were chipped off from chromium plated surface of the cylinder. Overall performance of Al-Bronze as bearing material was considered good. Figure 14 reveals few linear scratches on inner surface of cylinder.

4.2 Live-Firing Test and Analysis:

After simulation testing, the piston was then sent to Yuma Proving Ground, AZ for live-firing test where a total of 518 rounds were fired. At the conclusion of the test the recoil mechanism was disassembled and the piston was visually examined. It was observed that no adverse degradation of the piston had occurred. Only a few additional scratches were evident and none of these scratches were of any appreciable depth. The piston is considered in excellent condition for additional testing.

5.0 CONCLUSIONS:

The use of cast steel pistons clad with an aluminum-bronze bearing material will resolve prior failure problems experienced with nodular iron pistons currently used in the M174 recoil mechanism. GMAW of Ampco-trode 46 to cast steel pistons results in a competitively priced clad steel piston with no material/manufacturing deficiencies. For example, the intermetallics formed are minimal and do not degrade material performance, i.e., the bond strength of bearing material and its substrate is over twenty times stronger than conventional electric arc metallized coatings. In addition, subject to high pressure friction tests, the aluminum-bronze coatings have better wear resistance when compared to nodular iron.

Development of suitable GMAW procedures results in the cladding of an improved steel piston wherein the dilution of the aluminum-bronze bearing material with iron is kept well below critical levels. Consequently, the quality of the bearing material is maintained. Control of welding parameters and interpass temperatures eliminate re-heat treatment requirements since the bulk temperature of the steel substrate does not exceed the tempering temperature of 1100°F. In those areas at the interface where melting occurs, subsequent cooling is provided by the substrate and martensite is formed. Stress relief heat treatment of the material immediately after welding tempers the martensite and eliminates any undesirable residual stresses.

6.0 RECOMMENDATIONS:

Control of interpass and bulk temperatures of cast steel pistons is critical to the success when GMAW bearing materials to heat treated steel pistons. Although GMAW procedures developed in this program are cost competitive, the rate of deposition, with attendent cost reduction, could be increased significantly by developing procedures to use larger diameter welding wire.

7.0 FUTURE WORK:

During the second phase of this program additional clad steel pistons will be manufactured for field tests. GMAW procedures using larger diameter wire will be investigated. Other cladding processes using strip welding and explosive bonding methods will be evaluated to determine the least-cost manufacturing method. An Engineering Change Proposal will be submitted to recommend implementation of the selected cladding process in production.

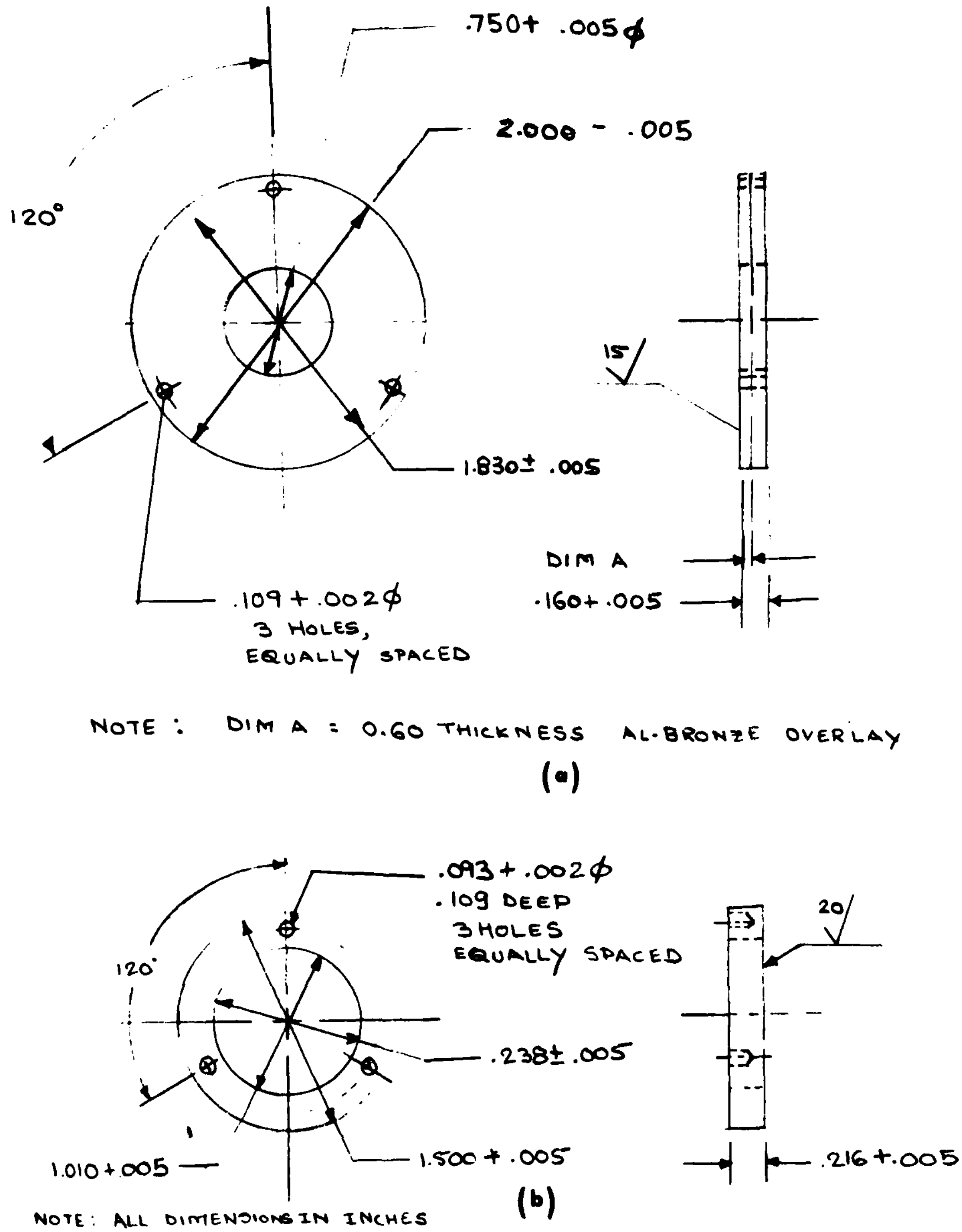
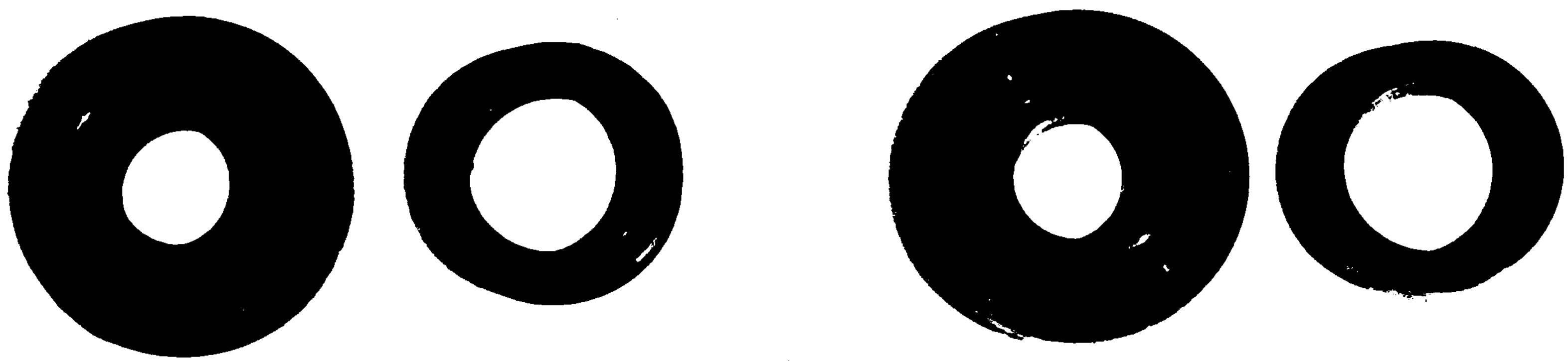


FIGURE 1. FRICTION & WEAR TEST SPECIMENS.
a. BEARING DISC b. MATING STEEL RING



Nodular Iron | 4130 Steel | Al-Bronze Overlay | 4130 Steel

(a) (b)

FIGURE 2. SHOWING WEAR ON SURFACES AFTER ONE-HOUR TESTS.
(a) NODULAR IRON VS. STEEL (b) AL- BRONZE OVERLAY VS. STEEL

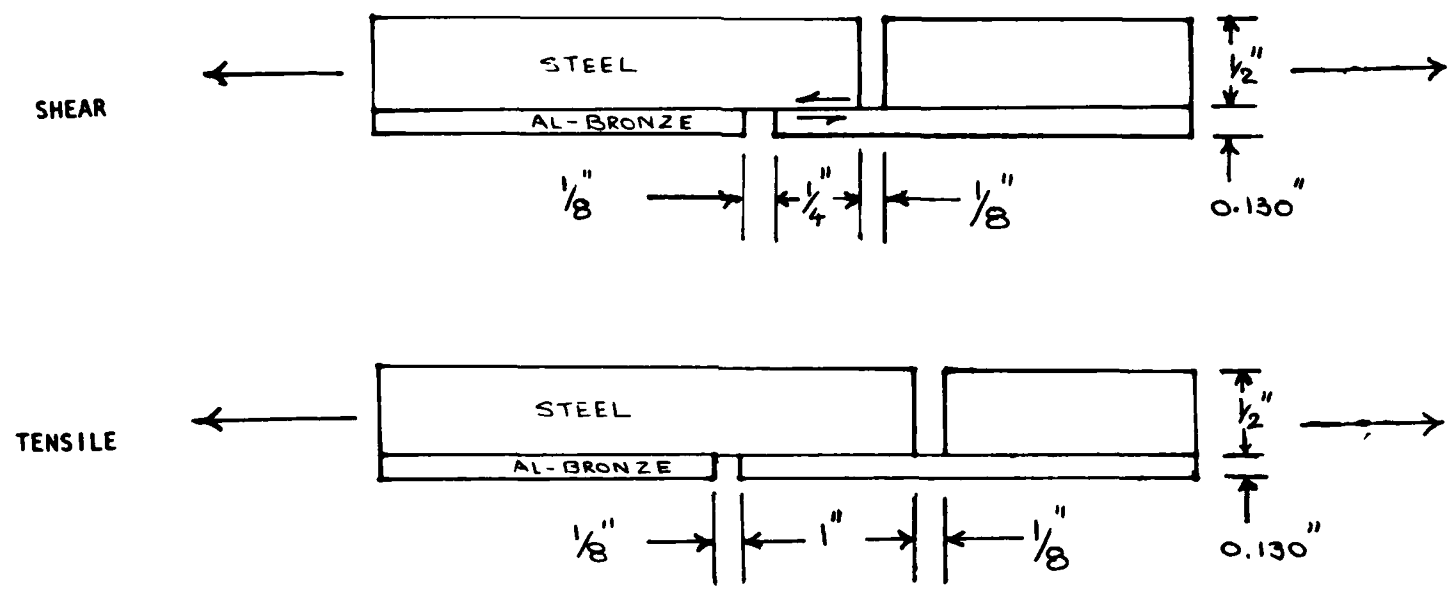


FIGURE 3. DIMENSIONS FOR SHEAR AND TENSILE TEST SPECIMENS.

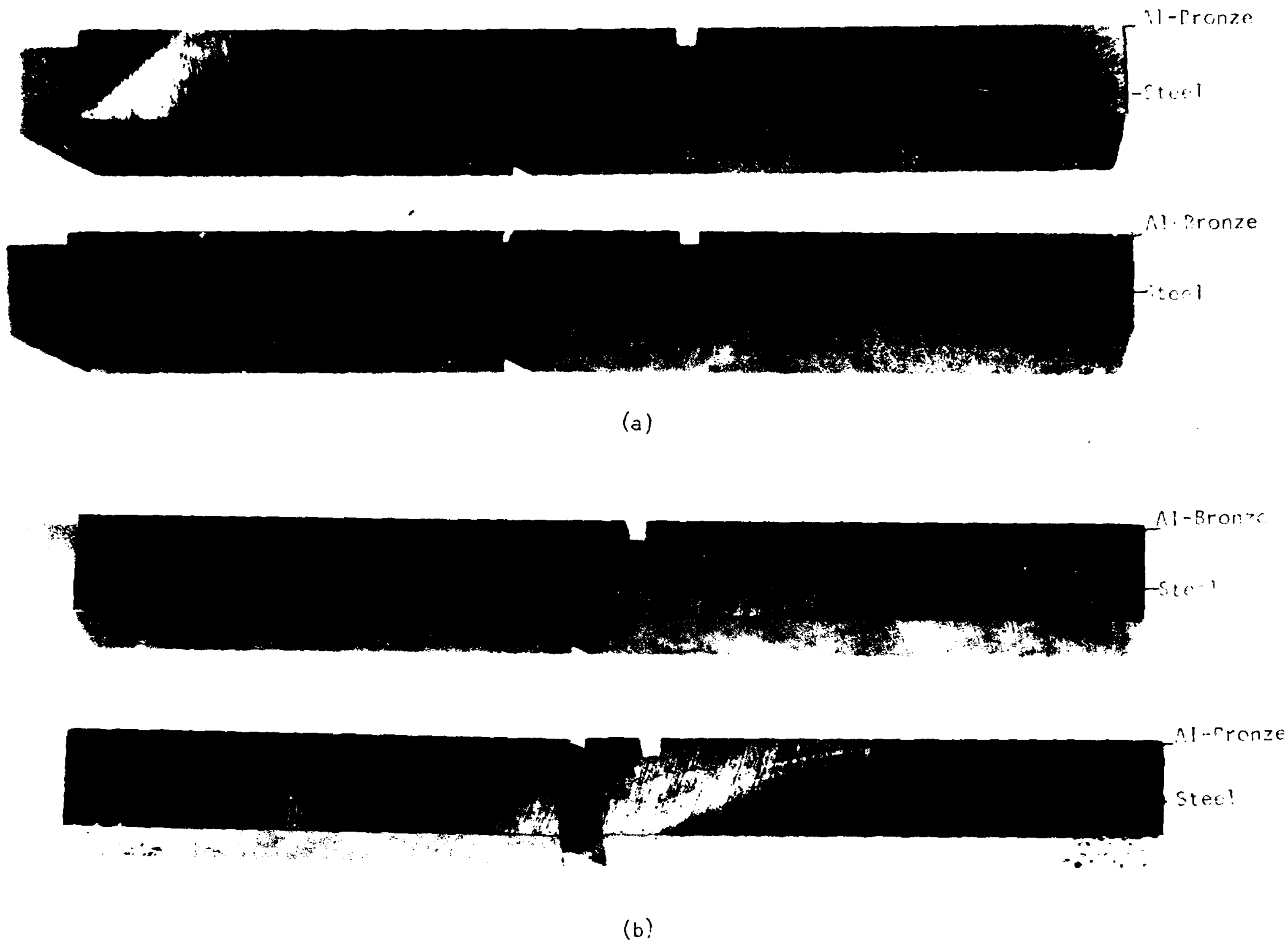
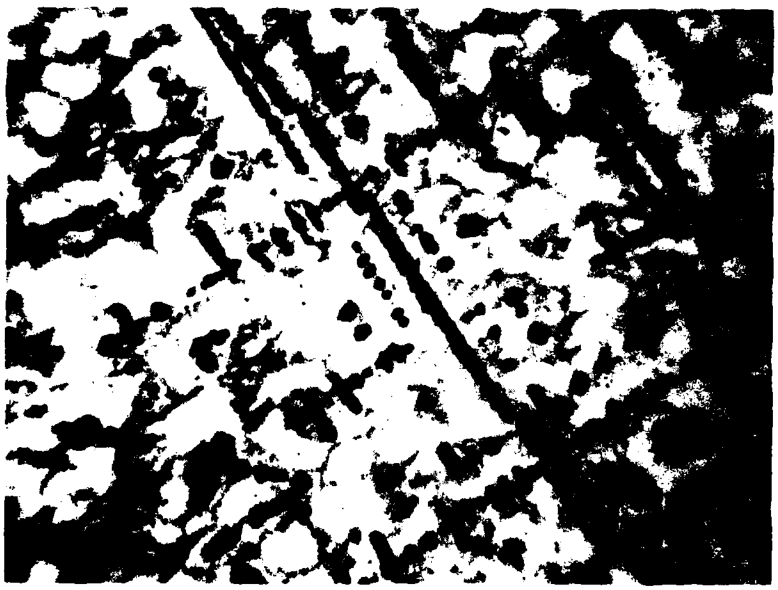


FIGURE 4. SPECIMENS BEFORE AND AFTER TESTS - (a) TENSILE TEST; (b) SHEAR TEST

(a)



(b)

FIGURE 5. MICROGRAPHS SHOWING COPPER-RICH DENDRITES IN Al-BRONZE OVERLAY. MAG.: a. 100X b. 800X, ETCHANT: $NH_4OH - H_2O_2$ (1:1)

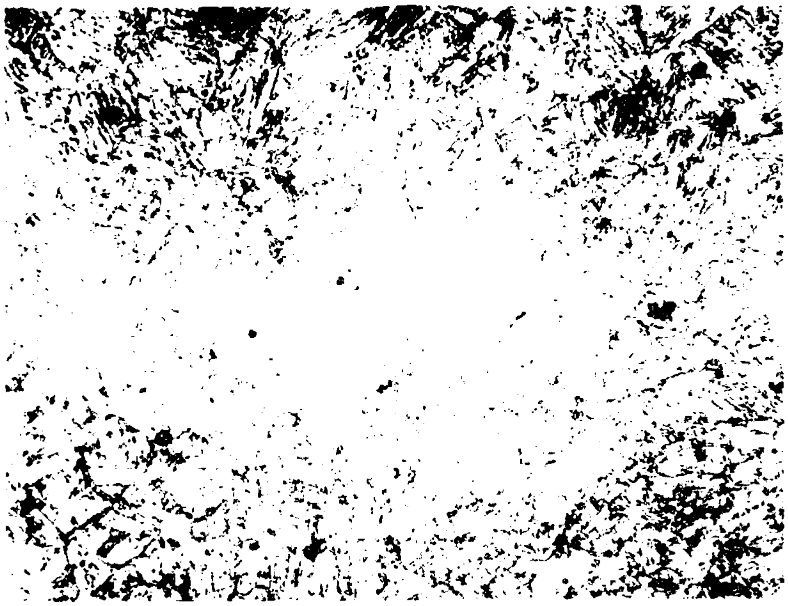


FIGURE 6. HEAT AFFECTED ZONE CONSISTS OF BAINITE AND FERRITE STRUCTURES. MAG.: 800X, ETCHANT: 2% Nital

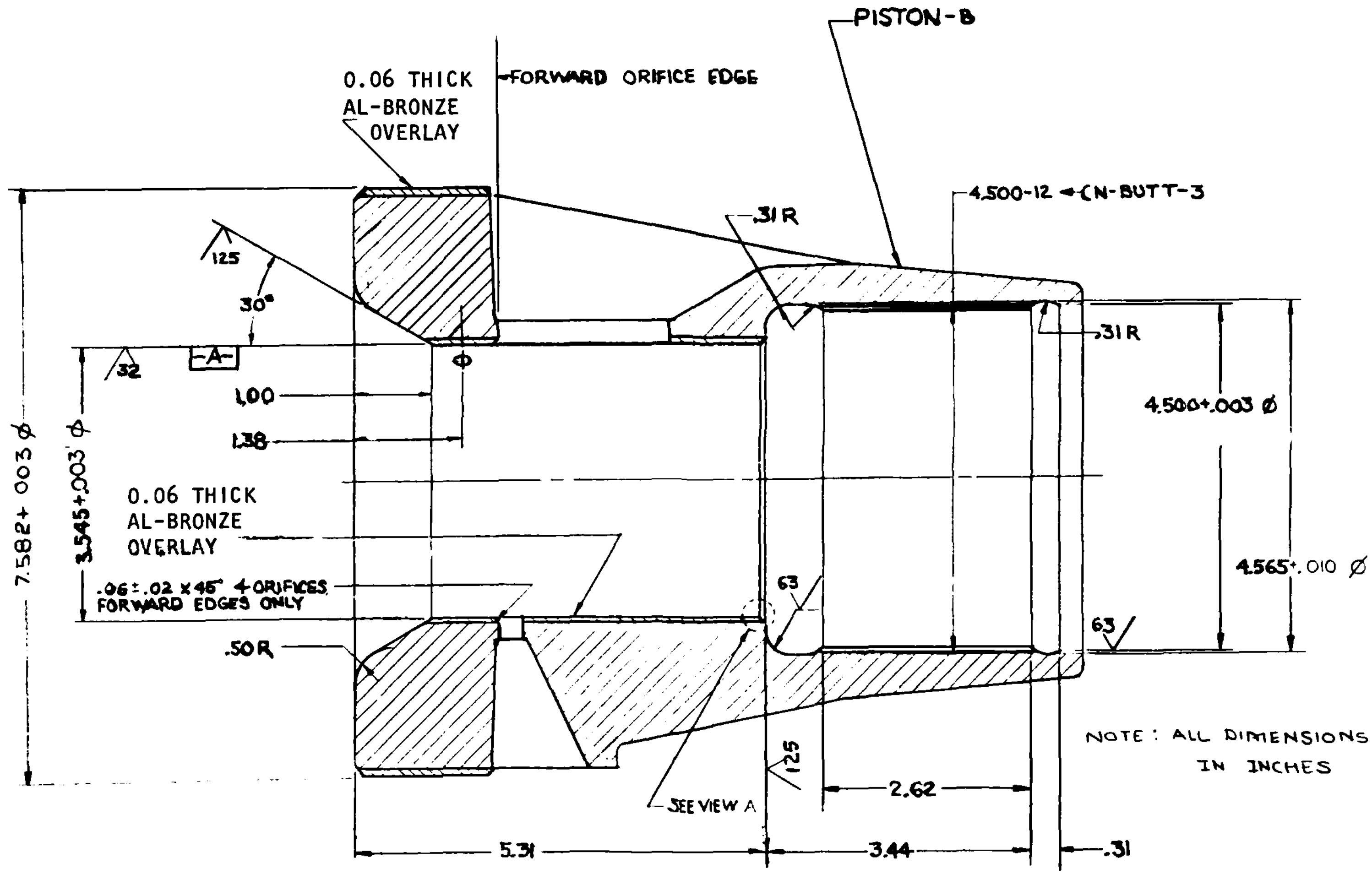


FIGURE 7. CROSS SECTIONAL VIEW OF RECOIL PISTON FOR M174 GUN MOUNT, COATED WITH BEARING MATERIAL.

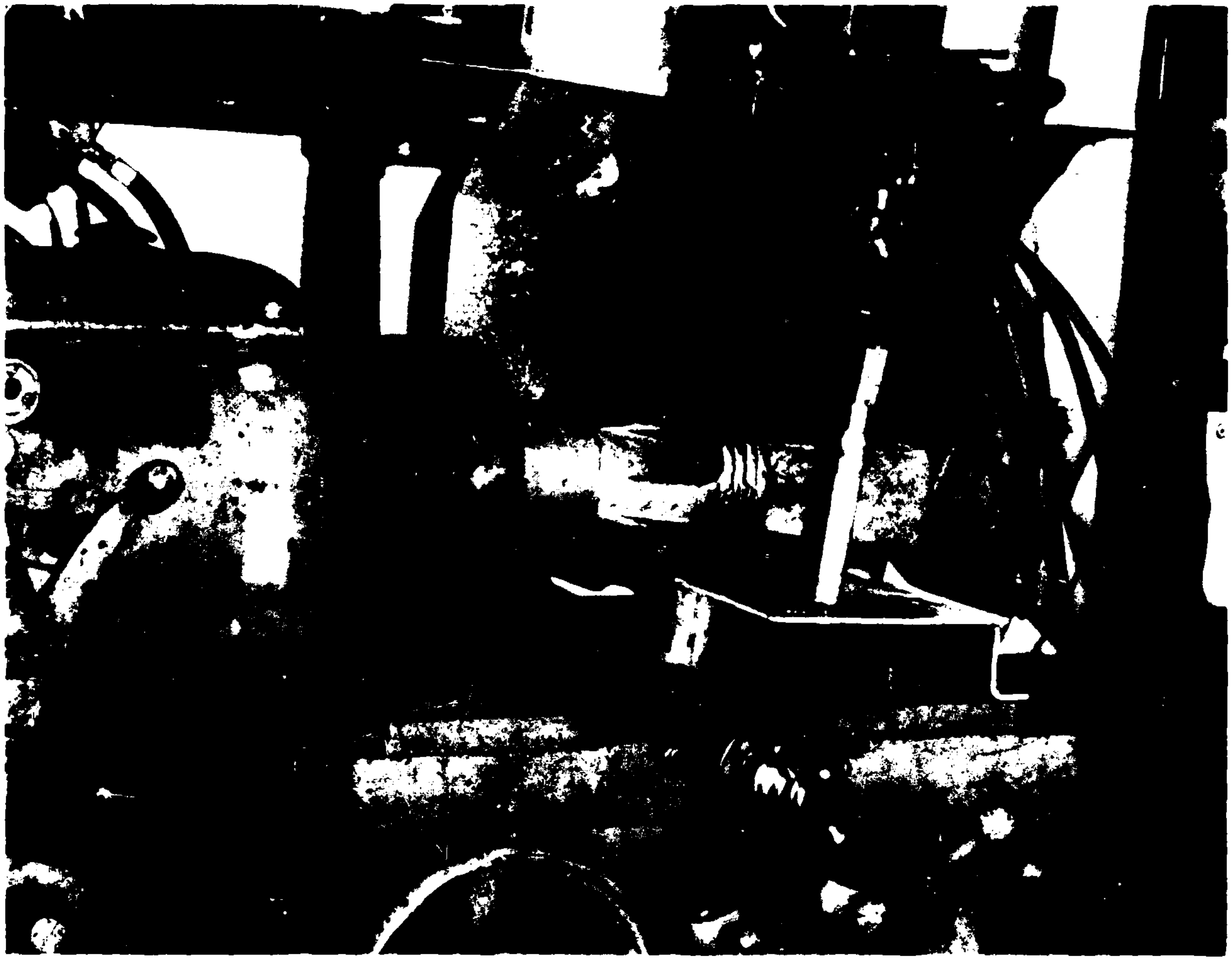
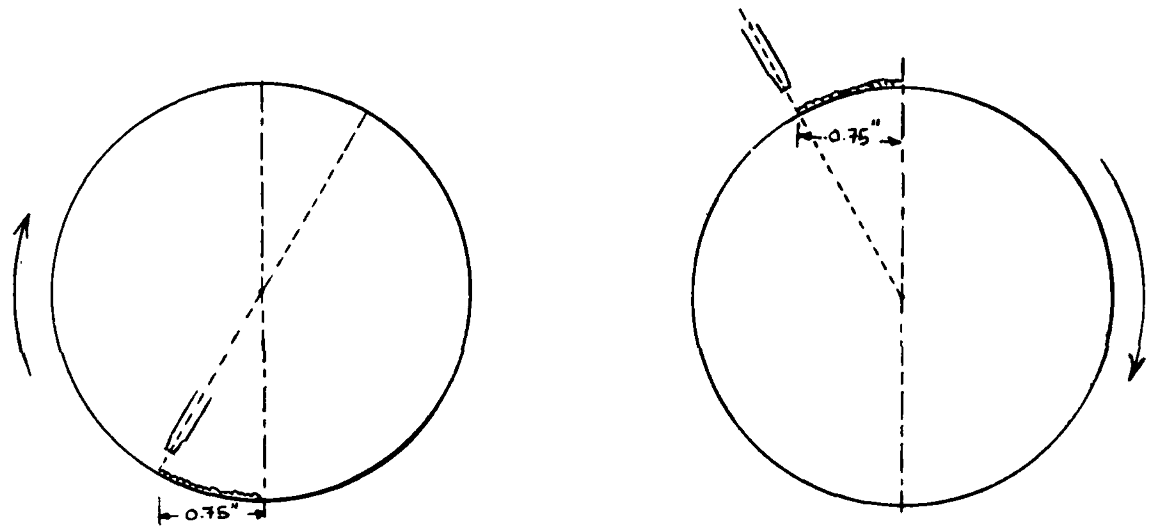


Figure 8. OVERALL SET UP FOR OVERLAYING AL-BRONZE ON M174 RECOIL PISTON USING GMAW PROCESS



a. INNER DIAMETER

b. OUTER DIAMETER

Figure 9. ILLUSTRATION OF TORCH POSITION LOOKING FROM REAR OF PISTON.

FIGURE 10. M174 PISTON COATED WITH Al-BRONZE (UNFINISHED).

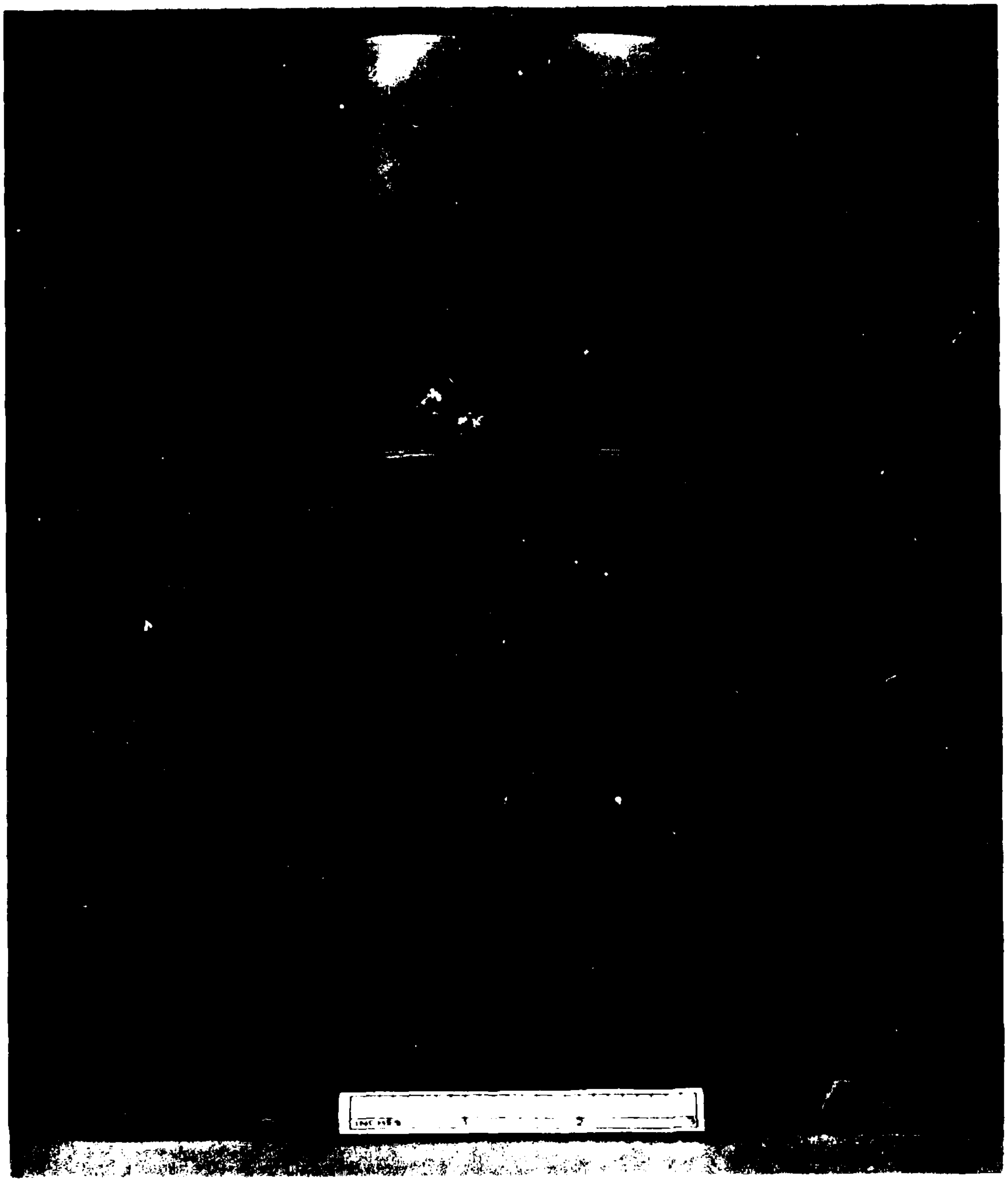


FIGURE 11. CROSS SECTIONAL VIEW OF M174 PISTON, COATED WITH AL-BRONZE ON O.D. AND I.D. SURFACES.

FIGURE 12. LIGHT SCORING ON OUTER BEARING SURFACE OF M174 PISTON AFTER TEST FIRING.

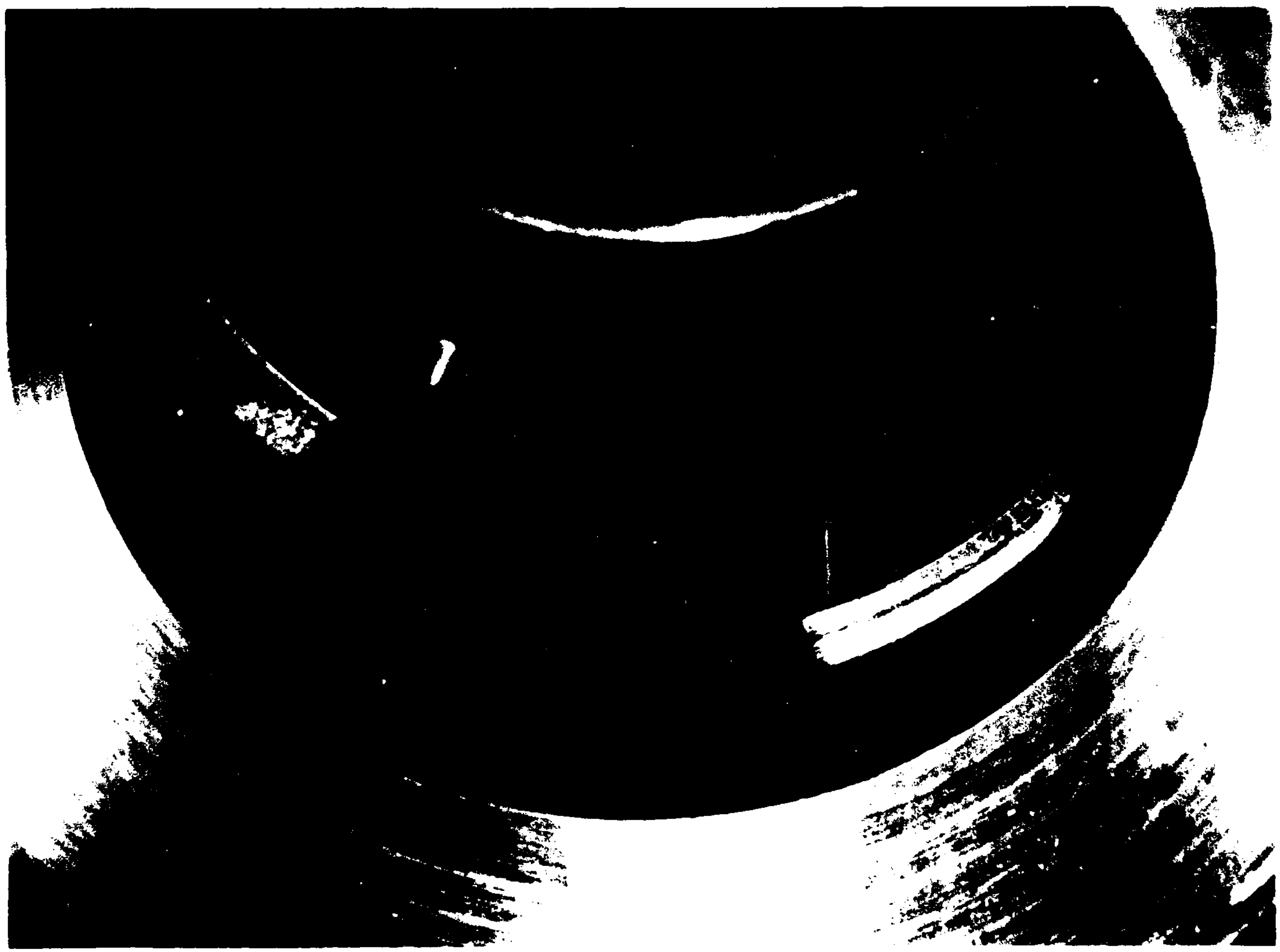


FIGURE 13. LIGHT SCORING ON INNER BEARING SURFACE OF M174 PISTON AFTER TEST FIRING.

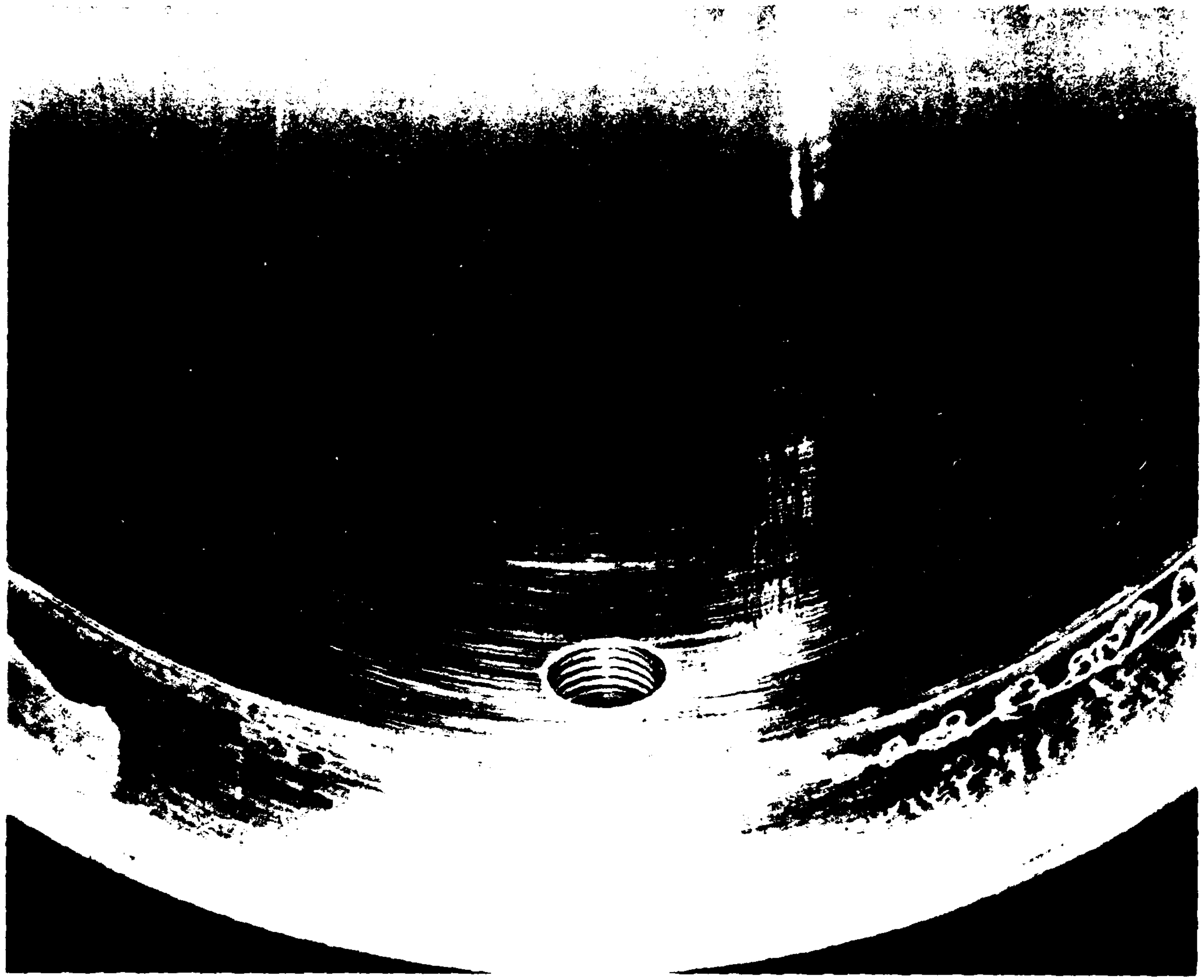


FIGURE 14. LINEAR SCRATCHES ON CHROMIUM PLATED SURFACE OF RECOIL CYLINDER AFTER TEST FIRING.

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Report EN-81-01, Oct 80, 29 p. incl. illus., tables, (AMS Code 4932.06.8035) Unclassified Report.

Nodular iron pistons for the M174 Recoil Mechanism characteristically yield less-than-desirable service lives; the deficiency being attributed to a lack of fracture toughness of the iron. Consequently, cast steel pistons clad with a bearing material, required since the steel does not offer the built-in lubricity indigenous to nodular iron, were considered as an alternate material.

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Future studies will provide more clad steel pistons for firing tests to verify material performance. In addition, strip welding and explosive bonding methods will be evaluated to determine the least cost method of cladding steel components with aluminum-bronze.

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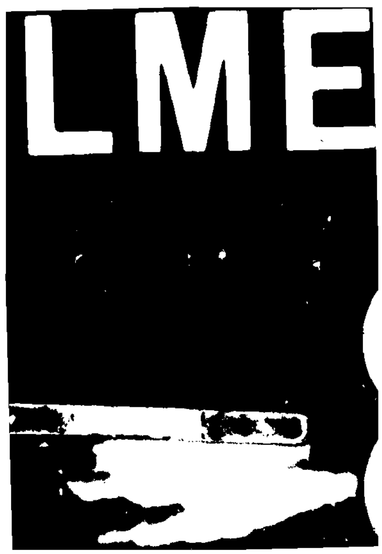
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